Technical Report
70-5-ES

CONTRIBUTIONS ON THE STATUS OF ARID-LANDS RESEARCH: GROUND WATER IN AUSTRALIA

by
Eugene S. Simpson
University of Arizona

Contract No. DAAG17-67-C-0199

August 1969

UNITED STATES ARMY
NATICK LABORATORIES

EARTH SCIENCES LABORATORY
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Earth Sciences Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

In November 1964 the Army Research Office awarded a contract to the University of Arizona for a comprehensive survey of the status of research on desert environments throughout the world, to be conducted by the University's Office of Arid Lands Studies. Monitorship of this contract was subsequently transferred to the Earth Sciences Laboratory of the U. S. Army Natick Laboratories and the results were submitted in a series of separate reports: Introduction, Weather and Climate, Desert Coastal Zones, Surface Materials, Vegetation, Geomorphology and Surface Hydrology, Fauna, Ground-Water Hydrology, and Desert Regional Types. All except the last were later revised and published by the University of Arizona Press under the title, Deserts of the World: An Appraisal of Research into their Physical and Biological Environments.

During the course of work on the contract described above a considerable amount of information was obtained on the status of ground water investigations in Australia. Owing to limitations of time, this material was not incorporated into the final report of the contract. Since the information was considered to have value to students of arid environments, the author, Dr. Eugene S. Simpson, and the Office of Arid Lands Studies have prepared it as a separate technical report. This report is published as one contribution under a later contract, No. DAAG17-67-C-0199, between the U. S. Army Natick Laboratories and the University.

The manuscript was reviewed by specialists in Australia at no cost to the U. S. Government, and their cooperation is acknowledged with appreciation.

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ABSTRACT

Essentially all exploitable ground water of the Australian arid zone is contained in the pore spaces of relatively flat-lying sandstones and limestones, which occur within the major sedimentary basins and cover about half of the arid-zone land surface. In each basin the aggregate thickness of the porous rocks is hundreds to thousands of feet, and they are interlayered with various rocks not bearing water, thus producing artesian or semiartesian conditions in many places. Although the quantity of stored water is immense, most of it accumulated during the past tens to hundreds of thousands of years; at least half of it is too mineralized for use in irrigation. The annual recharge from rainfall, though unknown in amount, is undoubtedly only a very small fraction of the amount in storage, and perhaps even less than the annual amount currently pumped from wells.

Outside the sedimentary basins, small to moderate supplies of ground water may be obtained from fissures in the older crystalline rocks, or from relatively thin surficial deposits of unconsolidated sand, if the local water table is not deeper than the depth of fissures or the bottom of the sand.

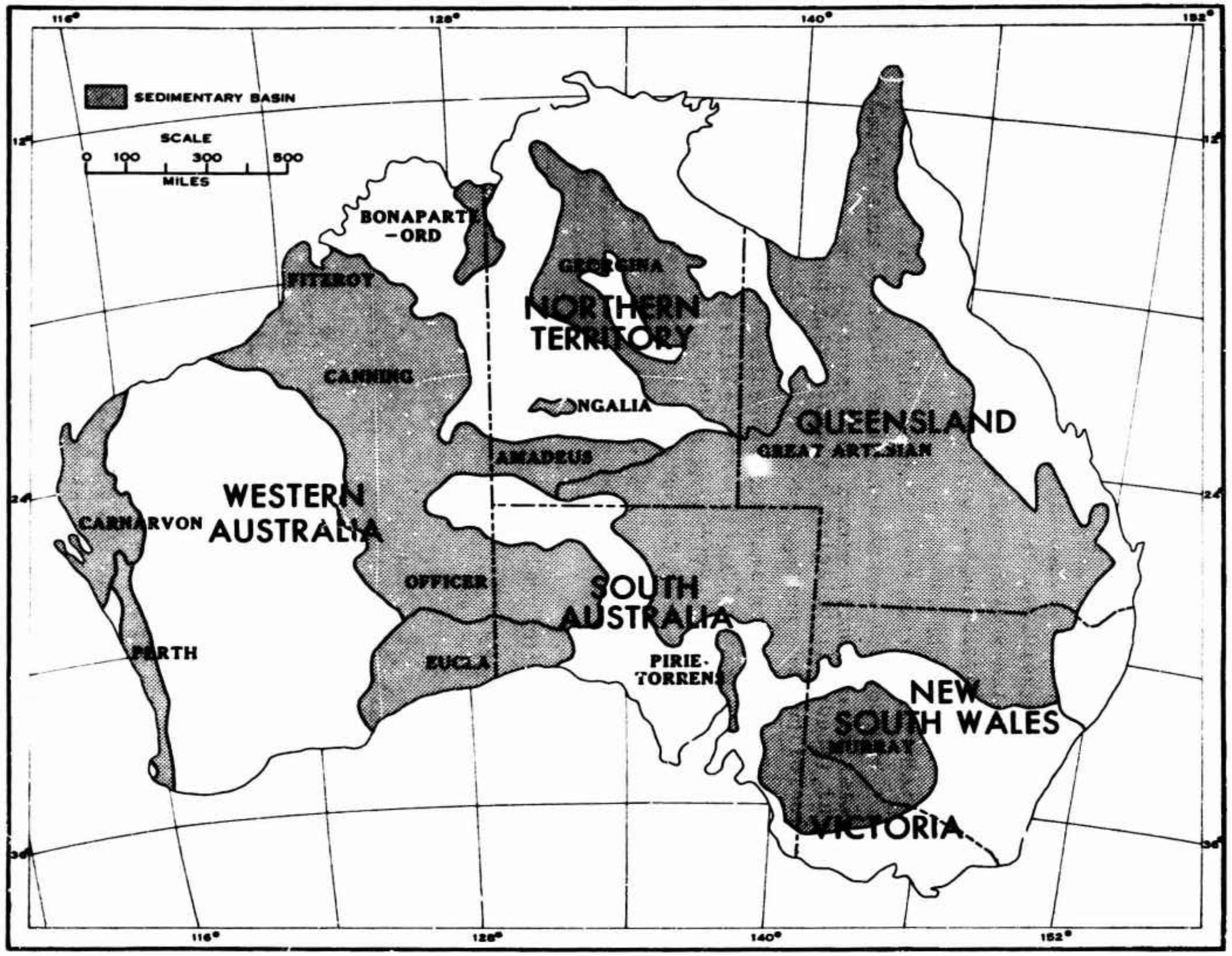

Figure 1. Sedimentary Basins Discussed in the Text
(adapted from Australian Water Resources Council, 1965)

CONTRIBUTIONS ON THE STATUS OF
ARID - LANDS RESEARCH: GROUND WATER
IN AUSTRALIA

Outline of Geology

The most recent general works on the geology of Australia are a text by Brown, Campbell and Crook (1968) and a map by the Tectonic Map Committee (Walpole, 1962). The map shows the generalized geology and structure of the entire continent. A set of notes that goes with the map contains, among other things, an extensive list of references to the geology. Also of importance, but now somewhat out of date, is the comprehensive outline of the geology of Australia by David (1950). The stratigraphy of Western Australia by McWhae _et al_. (1958) is of special importance. The discussion on Australia in King (1962) is useful but very generalized.

The Australian continent may be divided into three parts: (1) the Great Western Plateau (or Australian Precambrian Shield), covering the western and central parts of the continent, which includes three-fourths of the arid zone; (2) the East-Central Lowland (or Central East Depression), covering approximately the western halves of Queensland, New South Wales, and Victoria and overlapping into eastern portions of the Northern Territory and South Australia, which includes most of the remainder of the arid zone; and (3) the Eastern Highlands (or Tasman Geosynclinal Zone), covering roughly the eastern halves of Queensland, New South Wales, and Victoria, which except for a small section in central Queensland is entirely outside the arid zone. The foregoing names within parentheses are used to describe structural units, and the other names are used in referring to physiographic provinces. The paired names refer to essentially the same areas.

A review of water resources published by the Australian Water Resources Council (1965)* divides water-bearing rocks into three categories: (1) unconsolidated sediments; (2) porous rocks; and (3) fractured rocks. In a rough way this division coincides with geologic time boundaries in both the Great Western Plateau and in the East Central Lowland; besides, for purposes of a generalized review of ground water it is more convenient to discuss rocks in terms of their water-bearing characteristics than in terms of stratigraphic relationships. Generalizations are made to provide a readily

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* The Australian Water Resources Council plans to update this review and to issue a new set of ground-water resources maps in 1970.

understood overview of a subject that is most complex in detail. Statements made in this discussion of geology will have many exceptions, some of which will be noted in the discussion of ground water that follows.

Fractured rocks crop out over more than half of the Great Western Plateau and over nearly half of the Plateau and East-Central Lowland taken together. These rocks consist mainly of crystalline masses and metamorphosed and tightly folded sediments of Precambrian age. They are collectively referred to as the basement complex, and in areas where they do not crop out they underlie the younger and relatively undisturbed rock strata. Beginning in late Precambrian time, orogeny virtually ceased in the western half of the continent. Instead there developed a series of downwarpings or gentle basinlike depressions into which later sediments were deposited. The later sediments are continental and shallow marine, and except in a few areas are of no great thickness (meaning that total thickness is measured in thousands rather than tens of thousands of feet). The earliest shallow-basin rocks belong to late Precambrian time; however, in spite of their being relatively undisturbed, they are generally compacted and indurated to the point that recoverable water occurs mainly in fractures. Hence, all Precambrian rocks, including the relatively flat-lying strata, are included in the category of fractured rocks.

During Paleozoic time some of the older basins continued to subside, and, in addition, new basins formed. The sediments of the Lower Paleozoic consist mainly of sandstone, shale, dolomite, and limestone, and crop out over about ten percent of the arid zone. In places they are folded and faulted and are then generally classed in the category of fractured rock.

The rock units classed as porous are the sandstones and limestones deposited in the sedimentary basins from Late Paleozoic through Mesozoic and Tertiary times. Other rock types in the same age group but of low permeability are either classed among the fractured rocks, or are recognized and mapped as upper or lower boundaries to the permeable formations, or they are ignored. The porous rocks and interlayered beds of low permeability crop out over nearly fifty percent of the arid zone and contain enormous quantities of ground water. The major reasons that these rocks retained their relatively high permeability in spite of their age are (1) the continued absence of orogeny and (2) the relatively shallow depths of deposition. According to the Tectonic Map Committee (Walpole, 1962, p. 50): "From the end of the Permian, the Australian continent as a whole behaved as a craton; the tectonic stresses were resolved vertically rather than tangentially (broad shallow basins were formed), and the weak structural deformation in the Mesozoic is a direct expression of this stability. With the one exception of the Maryborough Basin on the east coast of the continent, there is no record of thick geosynclinal sedimentation in Mesozoic times." The stability of the continent was even

more pronounced during Tertiary time and the Committee goes on to state (p. 57): "A general result of the lack of orogenic movement in Australia since the end of the Paleozoic has been that, with the exception of the Eastern Highlands, the continent as a whole is now one of exceptionally low relief. Mostly, it is less than 2,000 feet above sea level, and the highest point--Mount Kosciusko in the Great Dividing Range in southern New South Wales--is less than 8,000 feet high."

Finally there are the unconsolidated sediments which range from Mesozoic through Recent. The bulk of these deposits consists of alluvial and eolian silts, sands, and gravels of Tertiary and Quaternary ages. They occur in the smaller basins, as valley fills, and as dunes (mostly now inactive). For the most part they are not adequately mapped and therefore no figure is available for their percentage outcrop area. Where they do occur, they cover the fractured or porous rocks mentioned above. Although the quantity of water contained in the unconsolidated sediments is far less than in the porous rocks, they offer a possibility of development far out of proportion to their mass, for the following reasons: (1) the quality of water is usually superior to that from most other subsurface sources; (2) they usually are more permeable than other sources; and (3) they often underlie topographic depressions and hence offer good opportunity for natural or artificial recharge.

Ground Water

The main outlines of Australian geology are reasonably well understood. For about two-thirds of the arid zone, however, there is no published data on ground water, and the writer must infer its occurrence from what is known of the geology and by analogy with other areas believed to be similar where data are available. The following discussion is based largely on the references previously cited.

Precise estimates of the maximum yields of wells are difficult to make because transmissive properties of aquifers are rarely measured except in areas of intensive exploitation. In fact, there may be no definite "maximum," because much depends on well depth, diameter, and construction. In general, however: (1) for fractured rocks, maximum yields are on the order of a few tens of gallons per minute, and in exceptional instances (such as for some volcanics) maximum yields may be on the order of a few hundreds of gallons per minute; (2) for porous rocks, maximum yields are on the order of a few hundreds of gallons per minute but in exceptional instances may be as high as a thousand or more gallons per minute; and (3) for coarse alluvium, maximum yield is on the order of a thousand or more gallons per minute. The published records for all three classes undoubtedly tend to underestimate average and maximum possible well

yields. This situation occurs because almost all wells are small-diameter holes, almost all only partially penetrate the aquifer, and, in the case of farm wells, the development of wells either is poor or absent. Also, in many cases the yield of a well is limited by the capacity of the pump used to test the well rather than by the well itself; consequently, the record will be a reflection of pump capacity rather than well yield.

The maximum depth of wells in fractured rock is limited by the depth to which fractures containing recoverable water exist or by the depth of weathering which, in places, creates porous zones. This depth is on the order of a few hundred feet. If the local water table is below that depth, then the possibility for obtaining recoverable ground water is nil.

Porous rocks may be encountered at depths of 10,000 feet or more, but wells rarely exceed 3,000 feet in depth. For the most part, the deeper beds contain water too saline for water supplies of any kind.

In unconsolidated sediments the depth of wells is ordinarily a few hundred feet. Eolian deposits are usually not more than 300 feet thick, but valley-fill alluvium and unconsolidated sedimentary beds may be a thousand feet or more thick.

The summary of ground water occurrences that follows is by major political subdivision: Western Australia, the Northern Territory, South Australia, Queensland, and New South Wales.

Western Australia: Fractured rocks occupy about 60 percent and porous rock about 40 percent of the land area of Western Australia. In addition, about 15 percent of these rocks are covered by unconsolidated sediments, mostly over the major basins, where the unconsolidated sediments are thick enough to extend below the local water table. A higher percentage is covered by unconsolidated sediments that are too thin to contain water. For perhaps 90 percent of Western Australia there is little or no published data on ground water.

Two major sedimentary basins containing porous rock strata face the Indian Ocean along the western edge of Western Australia. The Carnarvon Basin at the north is about 500 miles long (north-south) and about 150 miles wide (east-west), is slightly arcuate in outline, and has a total area of about 50,000 square miles. The rocks in this basin range in age from late Paleozoic to Tertiary. Ground water occurs almost everywhere, but at varying depths, and in the lower topographic portions the water is artesian where some flowing wells yield several million gallons per day. Water is generally poor, containing from 3,000 to 7,000 ppm (parts per million) of total dissolved solids in most places, except for a relatively small area in the northern part where water containing about 1,000 ppm may be obtained. For at least a third of the basin no published data at all

are available. More than a third of the basin is overlain by unconsolidated (eolian) sediments believed to contain water but whose water-bearing properties are unknown. Some data are available for alluvium in the channel of the Gascoyne River, which cuts across the middle of the basin flowing westward to the ocean. This alluvium, and also alluvium in several other westward-flowing streams, contains ground water of better quality than occurs in the underlying porous rock. There is also a coastal strip of unconsolidated sediment (dunes) some 150 miles long which yields moderate supplies of water of fair quality. At Carnarvon about 7 million gallons per day are pumped from the Gasgoyne alluvium and coastal dunes for domestic supplies and irrigation. In general, however, the ground water of the Carnarvon Basin is not suitable for irrigation but is satisfactory for livestock.

The Perth Basin, although contiguous to the Carnarvon Basin, is in effect a separate basin extending southward from it. The Perth is about 600 miles long (north-south) and about 50 miles wide, having a total area of 23,000 square miles; however, only the northern third of the basin is within the arid zone. The quality of water seems to be superior to that in the Carnarvon and in many places could be used for irrigation. Up to now it is little used except for stock. A coastal strip of unconsolidated sediment (dunes) of unknown water-bearing properties overlies the basin along almost all its length. Apparently there are no important deposits of river alluvium in this basin.

The area east of the Carnarvon and Perth basins, extending 1,000 miles north-south and 500 miles east-west, is occupied almost exclusively by Precambrian rocks. At least 10 percent of this surface is covered by unconsolidated eolian sediments and alluvium thick enough to extend below the local water table. A smaller percentage is covered by relatively thin playa or lake-bed deposits accumulated during periods when rainfall was sufficient to carry water and sediment to the closed depressions. Mostly they occur in the southern two-thirds of the region; they are typically long and irregularly narrow in plan view and range from a few miles to nearly a hundred miles in length. Altogether, an excess of 50 percent of the area is covered by unconsolidated sediments, including deposits too thin to contain water. Virtually no ground water data exist for this vast region of Precambrian rock and thin sediment. All that can be said is that small water supplies of variable but often satisfactory quality for domestic and stock use may be found in numerous places, and that in other (perhaps equally numerous) places, no water at all is found. In unusual locations, the weathering of granite may provide porous zones capable of yielding moderate supplies. Considering the area as a whole, ground-water supplies are extremely meagre.

The report of Chapman (1962) is an indication of what may be expected. A quick survey of some 25,000 square miles in the Meekatharra-Wiluna area

had identified seven or eight isolated alluvium aquifers, about 100 feet thick, overlying relatively impervious rock. Natural discharge from the aquifers is toward local ephemeral lakes, and their total catchment area was estimated to be 2,000 square miles. Chapman then spent three months studying two of the aquifers in somewhat greater detail. By extrapolation from these two aquifers he estimated an annual safe yield of about 20,000 acre-feet for the area as a whole. This represents enough water to irrigate about 0.025 percent of the area. Even if water yield could be increased severalfold by capturing storm runoff and artificially recharging it to the ground, it is still a meagre resource.

There is a strip of Precambrian fractured rock along the eastern boundary of Western Australia which is part of a larger body in the Northern Territory and will be discussed under that heading. The total area of fractured rock in Western Australia is about 590,000 square miles.

The remainder of Western Australia is occupied by all or parts of five basins: the Bonaparte-Ord, the Fitzroy, the Canning, the Officer, and the Eucla. The total thickness of deposits in these basins ranges from about 2,000 feet in the Eucla to about 30,000 feet in the Canning. Unconsolidated eolian sediments, thick enough to contain water, cover most of the Officer, about a third of the Canning, and minor portions of the others. Ground-water data exist for the Eucla Basin on the south and for the north ends of the Canning and Fitzroy Basins on the north, but for the region in between, about 700 miles north-south and 200 to 400 miles east-west, there exists virtually no data. In addition, not much is known of the geology of the Officer Basin, either.

The Eucla Basin, which borders the Pacific Ocean on the south side of Western Australia, is about 500 miles long (east-west) and about 200 miles wide. Its area is 73,000 square miles (including a portion in South Australia). The ground water in this basin is saline almost everywhere, ranging from 3,000 to more than 14,000 ppm total dissolved solids. Areas near the basin margins or in cavernous limestone near the surface may yield water of better quality. Information is generally lacking except along the Trans-Australian Railway line.

The Officer Basin, immediately north of the Eucla, is about 600 miles wide. Its area is 76,000 square miles in Western Australia. Most of it is covered with eolian sands yielding water that is generally saline, containing more than 14,000 ppm total dissolved solids. The quality of water in the underlying porous rocks is unknown.

The Canning Basin, to the north of the Officer, is about 600 miles long (north-south) and its width varies from about 200 in the south to about 400 miles in the north. Its total area is 183,000 square miles. Much of the ground water is under artesian pressure, but except for a

narrow coastal strip in the north end of it few data are available on quality. The north end contains water of fair quality, ranging from 1,000 to 3,000 ppm dissolved solids. In general, it appears that ample supplies for stock watering may be obtained almost everywhere in the basin. As mentioned, the Canning Basin is probably the deepest in the arid zone, containing about 30,000 feet of sediments.

The Fitzroy Basin on the northeast flank of the Canning is about 200 miles long (northwest-southeast) and about 100 miles wide. It contains water of fair quality throughout. The Bonaparte-Ord Basin in the northeast corner of Western Australia is mostly outside the arid zone. Its southern part, a region nearly 100 miles long and within the arid zone, contains water of fair to good quality available almost everywhere.

Northern Territory: The southern part of the Northern Territory, representing about two-thirds of its total area, lies within the arid zone. The area is underlain by about 60 percent porous and about 40 percent fractured rock. Perhaps 10 percent of the territory is covered by unconsolidated sediments thick enough to contain water. The principal basins are the Georgina, the Ngalia, the Amadeus Trough and the Great Artesian. Discussion of the Great Artesian Basin will be deferred to the section under Queensland.

The Georgina Basin occupies more than 30 percent of the arid zone of the Territory in its northeastern part, extending about 650 miles in a northwest-southeast direction and overlapping into Queensland. It covers an area of some 100,000 square miles. Over large areas of the basin, beds of Paleozoic limestone, dolomite, and sandstone, in which water is stored in joints and solution cavities, yield up to 100 gallons per minute to wells 200 to 1,000 feet deep. The Warramunga geosyncline, to the west of the Georgina Basin, contains small areas, totalling about 600 square miles, of Cretaceous and Tertiary rocks, yielding up to 200 gpm to wells up to 300 feet deep. These rocks overlie thick, generally metamorphosed, geosynclinal sediments of Precambrian age; however, the younger rocks provide the more useful aquifers. The water, which is of fair to poor quality, is used in places for municipal supplies and for irrigation. (A similar but larger area occurs to the south of the Ngalia Trough.) Virtually all of the water is used for livestock and domestic purposes, but it seems probable that larger supplies could be developed if desired. In the northwestern relatively humid end of the Georgina Basin, the water quality is good (less than 1,000 ppm dissolved solids); it changes to fair (1,000 to 3,000 ppm) in the central portion, and is poor (more than 3,000 ppm) in its southeastern end. For at least one-fourth of the basin, no water quality data exist

The Amadeus Trough occupies the southern border area of the territory, extends east-west for about 400 miles, covers about 48,000 square miles, and accounts for about 12 percent of the arid-zone area of the Territory.

This trough consists of strongly folded lower Paleozoic rocks. Reports indicate about 25 percent of the trough contains water of good to fair quality. For the remainder, the quality is poor or no data exist. There seem to be no published reports on yield or depth of wells. N. O. Jones (personal communication) reports that there is considerable recent interest in the possibility of "mining" groundwater in the Mereenie Sandstone (Devonian age). This sandstone is relatively permeable and contains water of good quality over large areas within the Trough.

South Australia: Except for a small portion along its southern border and southeast corner, all of South Australia is within the arid zone. Most of the western half is underlain by porous rocks of the Officer and Eucla basins (discussed above under Western Australia), and its eastern half is largely underlain by porous rocks of the Great Artesian Basin (discussed below under Queensland). About 125,000 square miles, or 33 percent of the state, are underlain by unconsolidated sediments which only locally provide sources of water of good quality. In most places these unconsolidated sediments overlie porous rock, especially in the western half of the state, but the underlying water is often saline. Not more than 3,000 square miles of unconsolidated sediment are known to contain water of good quality. The remainder either is unknown or contains water suitable for stock at best, or occasionally suitable for irrigation. Water yield, however, is often 400 gpm or more to individual wells.

Not counting the Great Artesian Basin, the porous rocks underlie about 56,000 square miles or 15 percent of the state. Only the Murray Basin in the southeast corner is known to contain important quantities of good water, and much of this is on the fringe or outside the arid zone. Some of the remaining basins contain good water, but they are quite small and are of local importance only. Fractured rock, occurring mostly in the central and south central part of the state, contain only small supplies, of which only a small part is suitable for stock or domestic use; hence, except for the Great Artesian Basin and miscellaneous small areas, the quality and yield of ground water in the arid zone of South Australia either is unknown or too poor for economic use. The most recent general summary is that of Ward (1946).

Queensland: The only significant aquifer within the arid zone of Queensland is the Great Artesian Basin. This basin is one of the largest of its kind in the world, covering more than 670,000 square miles. In addition to the part in Queensland (423,000 square miles), it extends into parts of the Northern Territory (33,000 square miles), South Australia (138,000 square miles), and New South Wales (80,000 square miles). In all it occupies more than one-fifth of the Australian continent. Its northern and eastern portion, constituting about one-third the total, and almost all in Queensland, is outside the arid zone. As a result, an arid region of some 400,000 square miles is underlain by a continuous reservoir of ground water.

As the name implies, many of the wells drilled into the Great Artesian Basin are flowing wells, yielding as much as a million gallons a day. Typically the water contains less than 3,000 ppm of total dissolved solids but is unsuited for irrigation because of a high percentage of alkali carbonates. Its widest application is for the watering of stock. Occasionally, small-scale irrigation is possible, especially where the soil is sandy, and in a few places it is used for municipal supplies. The basin is extensively drilled only in its eastern part, i.e., outside the arid zone. According to Hahn and Fisher (1964), there is less than one well per hundred square miles over most of the arid-zone area.

A brief description of the basin is given by Slatyer and Mabbutt (1964) as follows:

> It is a complex basin, with three main aquifers consisting of sandstones ranging from Triassic to lower Cretaceous in age and with Cretaceous shales forming the main aquiclude. The main intake area is in the east of the basin, where the sandstones outcrop over an area of 40,000 square miles between 1,000 and 2,000 feet above sea level and with an average rainfall of 25 inches. River floodouts provide a smaller intake in the northwest and west of the basin, where the aquifer is at the surface. The deepest part of the structure is in the southwest, where the basement rocks are 7,000 feet below sea level in Lake Eyre. Bores are more than 4,000 feet deep in this area. The surface form of the basin corresponds largely to its structure, so that the direction of subsurface flow accords closely with the surface drainage. There is a northern component tributary to the Gulf of Carpentaria, while the remainder is directed southwestward to Lake Eyre or south-southwestward along the line of the Darling River. The piezometric level is never far above the topographic surface. The natural outlets of the artesian waters are the calcareous mound springs which occur in the lowest parts, as in Lake Eyre, and also at rises in the level of the basement rock.

Slatyer and Mabbutt give the total area of the basin as 580,000 square miles; apparently, they exclude much or all of the Carpentaria Basin from their calculation.

According to a report submitted by a Committee of Investigation (Queensland, 1954), the estimated "permanent yield" of the Queensland portion of the basin, including regions outside the arid zone, is about 110 million gallons per day. For the entire basin the estimate made is 125,000 million gallons per day. Hence, it appears, as may be expected, that recharge to the basin within the arid zone is only a small fraction of the total. Much of the recharge entering the aquifer in the more humid

eastern part percolates westward into the arid part, but the rate of flow is slow and the time of travel from recharge area to discharge area is probably on the order of tens of thousands to hundreds of thousands of years. The assumption has been made that the water pumped from the aquifer, if high in carbonate, has been recharged from the eastern end; if high in sulphate, then from the western end (Ward, 1946); however, this distinction is now disputed by some South Australian hydrologists (N. O. Jones, personal communication). Apparently, there is reason to believe that no significant recharge occurs in South Australia; i.e., from western end of basin. Even though the rate of recharge is low, there is little danger of seriously depleting the reserve unless water is withdrawn on a scale far greater than now expected. The principal inconvenience thus far is the need to pump in some areas where discharge has lowered the artesian pressure to below land surface. Little or no change either in water quality or in water temperature has been noticed in any area of long-term production.

New South Wales: Except for a portion in its northwest corner which is occupied by the Great Artesian Basin, and a zone of about 50,000 square miles between that basin and the Murray Basin to the south, New South Wales is outside the arid zone. The zone between the two basins is underlain by fractured rock, much of which is covered by unconsolidated sediments. These deposits yield small supplies of water, mostly containing more than 3,000 ppm of dissolved solids, but fresher water occurs in and near areas of relatively high ground near its western boundary.

Summary

The Australian Water Resources Council (1965) figures show that as of 1963 the occurrence of water and water quality was unknown for more than 50 percent of the arid zone. For most of the remainder, occurrence and quality were only imperfectly known. In recent years, however, the level of investigational and research activity has been increased. Today, the general level of knowledge of the ground-water resource undoubtedly is higher than that indicated by the above-quoted 1965 summary. Evidence of the increased knowledge should become apparent in reports scheduled for publication within the coming few years. Although much remains to be done by way of preliminary exploration, this effort is being aided by petroleum exploration, mostly accomplished during the past decade, and by regional geologic mapping begun on a systematic basis some two decades ago.

Subsurface data are expensive to obtain. Well drillers who drill for private farms or domestic water supplies are not usually equipped to make careful geological and hydrological observations. Even if they were so equipped, the owners for whom the wells are drilled probably would be unwilling to bear the added cost involved. Exceptions to the general rule

of drilling wells for water production to the neglect of water information are areas where strong state control is exercised over resource development. In Queensland, for example, conservation regulations have been in force for several decades requiring, among other things, that artesian wells not be permitted to flow to waste. There is a tendency in Australia, as elsewhere, for greater state involvement in the private drilling and utilization of wells. Such state involvement should gradually improve the quality and increase the quantity of basic hydrogeologic data. The various Australian agencies involved in ground-water investigations appear to be shifting emphasis from preliminary areal exploration to more careful measurement and problem-solving. This is also occurring in the United States, but an estimate of the effort devoted to each type of activity is not readily available.

Up to now, little attention has been given in Australia to the problem of ground-water quality, other than the usual tabulation of results of chemical analyses and the determination of the suitability of the various waters for various possible uses. Australia provides many interesting and intriguing problems relating to the origin and distribution of chemical elements in ground water, not the least of which is that of the Great Artesian Basin. This type of research apparently is left in abeyance until problems arise connected with artificial recharge, contamination, reuse of water, etc., and when the mere tabulation of quality analyses is no longer sufficient for the needs of water management.

The list of references for Australia fall into two general categories: (1) relatively detailed descriptions of small areas, and (2) generalized summaries of a basin, a state, or the whole continent. Other than the work done on the Queensland (1954) portion of the Great Artesian Basin, there seems to be no published compendium of detailed information covering a large area. A difficulty in information access that Australia shares with many other countries, including the United States, is that responsibility for ground-water investigations is divided among the various states and various agencies within the states, plus the Commonwealth and its various agencies. There results a multiplicity of publication sources and information sources; moreover, only a small fraction of basic data ever reaches publication. Complete files of the published reports are maintained in very few libraries, if any, outside the country of origin.

Agencies Responsible for Ground-Water Investigation in the Arid Zone of Australia

(Names of local experts are given in parentheses; however, most government authorities prefer all correspondence to be addressed to the Secretary or Director, as appropriate, even if marked to the attention of an individual.)

New South Wales

1. Water Conservation and Irrigation Commission (Sydney). Among other things, the Commission is responsible for locating, investigating, developing and utilizing ground water throughout the State. (Mr. W. H. Williamson)

2. Department of Mines (Sydney). The Hydrology Division of this Department undertakes field investigations and measurements of ground water resources; water quality analysis is performed by the Chemical Laboratory.

Queensland

1. Irrigation and Water Supply Commission (Brisbane) is the principal authority responsible for the investigation and control of ground water resources. (Mr. G. Pearce)

2. Department of Development and Mines (Brisbane), carries out hydrogeological investigations and assists with water supply investigations.

South Australia

1. Department of Mines (Adelaide). The Geological Survey Branch of the Department conducts aerial investigations of ground-water resources. (Mr. C. Bleys)

Western Australia

1. Department of Public Works and Water Supply (Perth) is responsible for water supply, irrigation, and land drainage, and undertakes developmental work and administration of ground-water resources.

2. Department of Mines (Perth) performs some surveys of the State's ground-water supplies. (Mr. E. O'Driscoll)

3. Geological survey performs nearly all ground-water investigations.

Northern Territory

1. Water Resources Branch, Northern Territory Administration (Darwin), is responsible for the investigation, development, and control of the ground-water resources of the Territory. (Mr. I. Binch)

Australian Capital Territory

1. Bureau of Mineral Resources (Canberra), undertakes the systematic study of ground water in and around the Australian Capital Territory. The Australian Capital Territory is outside the arid zone, but the Bureau of Mineral Resources provides staff for the geological side of ground-water work in the Northern Territory and conducts regional geological and geophysical surveys in northern Australia.

Miscellaneous

1. Commonwealth Scientific and Industrial Organization, Land Research and Regional Survey Division (Canberra). This is a quasigovernmental organization that performs various kinds of research, including ground-water research. (Dr. T. G. Chapman)

2. The Technical Committee on Underground Water. (Secretary: G. F. Clarke, c/o Bureau of Mineral Resources, Canberra). This is the advisory committee on ground water to Standing Committee of the Australian Water Resources Council. Its members represent all the major State and Commonwealth authorities engaged in ground-water studies in Australia.

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13. ABSTRACT

Essentially all exploitable ground water of the Australian arid zone is contained in the pore spaces of relatively flat-lying sandstones and limestones, which occur within the major sedimentary basins and cover about half of the arid-zone land surface. In each basin the aggregate thickness of the porous rocks is hundreds to thousands of feet, and they are interlayered with various rocks not bearing water, thus producing artesian or semiartesian conditions in many places. Although the quantity of stored water is immense, most of it accumulated during the past tens to hundreds of thousands of years; at least half of it is too mineralized for use in irrigation. The annual recharge from rainfall, though unknown in amount, is undoubtedly only a very small fraction of the amount in storage, and perhaps even less than the annual amount currently pumped from wells.

Outside the sedimentary basins, small to moderate supplies of ground water may be obtained from fissures in the older crystalline rocks, or from relatively thin surficial deposits of unconsolidated sand, if the local water table is not deeper than the depth of fissures or the bottom of the sand.

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